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ATTACHMENT 1

EFFECT OF DEVELOPER COMPOSITION ON THE STRUCTURE OF PHOTOGRAPHIC IMAGES

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Effect of Developer Composition on the Structure of Photographic Images

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Two microstructure properties of the photographic image — acutance and granularity — were examined as functions of developer composition for three black-and-white 35mm films. Systematic variations in developer composition were made to explore the effects of the concentration of sulfite and of *p*-methylaminophenol independently. The resulting changes in sharpness and graininess were found to depend on the particular emulsion involved. The effects of simultaneous changes in these two quantities were estimated on two different bases to find optimum film–developer combinations both for general photography and from the standpoint of informational sensitivity.

It is well known that the graininess of photographic materials is affected by the composition of the developer in which they are processed, and since the advent of the miniature camera, many studies of fine-grain development and developers have appeared in the literature. Although it was noted[1,2] more than fifteen years ago that the sharpness of the photographic image is sometimes reduced by fine-grain development, this aspect of development seems to have attracted little attention until comparatively recently.

The great expansion of miniature photography and the increasing capabilities of modern lenses and emulsions, however, have caused renewed interest in the possibilities of developing for improved sharpness, and a number of formulas giving such improvement have been devised and marketed in recent years. These mostly appear to be of the type described by Beutler,[3] which contain *p*-methylaminophenol developing agent and sulfite in low concentrations.

But practical experience with special-purpose developers has shown that they often work at cross purposes; a gain in one emulsion characteristic is accompanied by losses in other characteristics which are also of interest. The loss in sharpness, just cited, that sometimes occurs as a result of fine-grain development is an example. Conversely, the use of high-sharpness developers generally results in increased graininess. Since, of course, it is desirable to improve both qualities simultaneously, it seemed useful to investigate the properties of both fine-grain and high-sharpness developers. Furthermore, where incompatibility between desirable properties occurred, it seemed desirable to investigate methods of choosing the best compromise. Accordingly, two series of experiments were arranged, using developers in which one property was varied systematically while others were held (as far as possible) constant.

The first series of developers was a "fine-grain" group. One common method of producing a fine-grain developer is to add a silver halide solvent to the solution; this was the method chosen for these experiments. The solvent used was sodium sulfite. The second series was a group of high-sharpness formulas. Such developers act by producing increased adjacency effects; one way to achieve this is merely to reduce the concentration of the developing agent, which in the present study was Kodak Elon* Developing Agent, and this was done progressively through the series.

The image-structure properties selected for study were the graininess and sharpness of the various samples processed to matched gammas in the various developers. Previous work carried out in these Laboratories had shown that the comparative effects of two developers were not the same for all emulsions, which means that it is not possible to generalize with respect to such results. Therefore, tests were carried out on the three Kodak black-and-white emulsions then available for 35mm amateur photography: Kodak Panatomic-X Film, Kodak Plus-X Film, and Kodak Tri-X Film.†

Communication No. 2138 from the Kodak Research Laboratories. Presented at the National Conference, Chicago, 28 October 1959. Received 7 December 1960.

1. R. W. Henn and J. I. Crabtree, *J. Phot. Soc. Am.*, **10**: 727 (1944).
2. H. Harvey, "Development and Developers," in *The Complete Photographer* (W. D. Morgan, ed.), **4**: 1267 (1942).
3. W. Beutler, *Leica Photographie* (English ed.), Sept.-Oct. 1953, p. 182.

* Kodak Elon Developing Agent is the Eastman Kodak Company trade name for *p*-methylaminophenol sulfate.

† The data presented in this paper are representative of the emulsions manufactured at the time the experiments were made. However, it must be recognized that the characteristics of products of the same name may vary within manufacturing tolerances and may change significantly as improvements are effected.

Experimental Details

Developer Formulas. The first step in the experiment was to formulate the appropriate series of developers. This was done by the sensitometric testing of preliminary formulas with the aim of establishing reasonably uniform activity levels and development times. The first section of Table I shows the composition of the fine-grain series (Series I).

TABLE I. Constituents of Developers

Series	Formula No.	Kodak Elon (g/l)	Sodium sulfite (anhydr.) (g/l)	Sodium bisulfite (g/l)	Total sulfite (M/l)	Kodalk (g/l)
I (fine-grain)	AH-1	7.50	10	0	0.08	4
	AH-2	7.50	30	5	0.29	0
	AH-3	7.50	100	15	0.95	0
	AH-4	7.50	200	20	1.80	0
II (high-sharpness)	AH-15	2.50	10	0	0.08	4
	AH-16	1.00	10	0	.08	6
	AH-17	0.50	10	0	.08	20
	AH-18	0.25	10	0	.08	20

The central formula in this series, AH-3, is essentially Kodak Developer D-25.[4] It is a true fine-grain developer, giving grain reduction at the expense of reduced emulsion speed. The solvent action has been lowered in the AH-1 and AH-2 formulas by decreasing the sulfite content. Since this reduction would lower the pH and the activity as well, most of the bisulfite was removed in AH-2 and Kodalk Balanced Alkali was added in AH-1. Formula AH-4 contains more than the usual amount of bisulfite. This maintenance of approximately constant activity was considered essential since Henn and Crabtree[1] have shown that graininess is affected by both activity and sulfite content.

The solvent action is obtained from the combined effect of the sulfite and bisulfite, and these are totaled as moles of sulfite ion in the table.

The composition of the second series of developers is given in the second section of the table. These developers are of the "high-sharpness" type, characterized by low sulfite content and decreasing Elon content. The AH-16 developer, containing 1 gram of Elon per liter, is similar to the Beutler high-sharpness developer, which contains 0.83 gram of Elon per liter of diluted developer; both AH-16 and Beutler's formula have low sulfite content and moderate alkalinity. The Elon contents of the AH-1, 15, 17, and 18 developers bracket this, varying from 7.5 to 0.25 grams/liter. They all contain 10 grams of sodium sulfite per liter and the proper amount of alkali to equalize the activity. Full compensation of activity was not possible in the case of AH-18, containing the least amount of Elon, but the others are matched reasonably well.

Procedure. Once the final formulas had been established, complete time-gamma studies were made, and times of development at 68°F for a gamma of 0.65 for all emulsion-developer combinations were chosen. Acutance, granularity, and sensitometric-control strips were then exposed and processed for the times indicated by these studies. Processing was in the sensitometric machine of Jones, Russell, and Beacham,[5] which gives strong and uniform agitation. The resultant strips were evaluated in accordance with standard practices described in the literature. The speeds which will be cited later in the paper are $0.3\bar{G}$ speeds measured according to the familiar ASA criterion. Granularity was measured in terms of the root-mean-square of the granularity fluctuations.[6] The diameter of the scanning aperture was 24 μ and the sample density was unity. Acutance was measured as described by Perrin;[7] the sample density was also unity. Since the curve shapes were similar, a single number at a constant density is a reasonable indication of the behavior of the developers.

Results

The results are summarized in Tables II–IV, which give the results for Panatomic-X, Plus-X, and Tri-X Films, respectively. Kodak Developer D-76 is included for comparison[4] and is taken arbitrarily as 100%. The sulfite concentration is given in grams per liter. The data for AH-1 in Series I are repeated in connection with Series II because, in a sense, this developer also forms a part of the latter series.

Speed, Acutance, and Granularity. The results for the fine-grain series, AH-1 to AH-4, are shown in Fig. 1, where they are plotted on the basis of 100% for AH-1. The abscissas are in terms of moles of sulfite ion per liter. As the sulfite concentration is increased, the speed and the granularity (top and bottom graphs) of all three emulsions diminish to a minimum at about 1.0 mole/liter and then rise again. The broken line shows the rate of solution of silver as determined by Lee and James,[8] and this exhibits a maximum at about 0.6 mole/liter. Although the data are not sufficient to locate the minima for speed and granularity precisely, these minima fall near the maximum rate of solution, and the proximity may be regarded as more than accidental. (The speed curve for Tri-X Film as drawn does not show a minimum, but the data are insufficient to determine whether there may be a minimum between 1.0 and 1.8 moles/liter.) The curves of acutance

4. *Processing Chemicals and Formulas*, Eastman Kodak Company, Rochester, N.Y., 5th ed., 1954, p. 39.

5. L. A. Jones, M. E. Russell, and H. R. Beacham, *Jour. SMPE*, **28:** 73 (1937).

6. G. C. Higgins and K. F. Stultz, *J. Opt. Soc. Am.*, **49:** 925 (1959).

7. F. H. Perrin, *Jour. SMPTE*, **69:** 151 (1960).

8. W. E. Lee and T. H. James, private communication

TABLE II. Speed, Acutance, and Granularity of Kodak Panatomic-X Film

	Formula No.	Kodak Elon	Sulfite (g/l)	Dev. time (min)	γ	Speed	Speed %	Acutance	Acutance %	Granularity	Granularity %
Series I (fine-grain)	AH-1[a]	7.50	10	9	0.62	130	113	2340	106	0.027	123
	AH-2	7.50	30	8	.63	125	108	2200	100	.019	86
	AH-3	7.50	100	8¼	.63	82	71	2200	100	.011	50
	AH-4	7.50	200	11	.63	96	83	1850	84	.012	55
Series II (high-sharpness)	AH-1*	7.50	10	9	0.62	130	113	2340	106	0.027	123
	AH-15	2.50	10	4	.61	107	93	2500	113	.034	155
	AH-16	1.00	10	5	.61	117	102	2550	116	.036	164
	AH-17	0.50	10	7	.69	129	112	2750	125	.036	164
	AH-18	0.25	10	13	.64	150	130	3100	141	.034	155
Kodak Developer D-76 (1:1)[b]				6½	0.62	115	100	2200	100	0.022	100

All data from single runs except for:
a. average of 5 runs; b. average of 2 runs.

* Data repeated for convenience.

TABLE III. Speed, Acutance, and Granularity of Kodak Plus-X Pan Film

	Formula No.	Kodak Elon	Sulfite (g/l)	Dev. time (min)	γ	Speed	Speed %	Acutance	Acutance %	Granularity	Granularity %
Series I (fine-grain)	AH-1[a]	7.50	10	12	0.68	340	128	1820	96	0.044	147
	AH-2	7.50	30	9½	.62	224	84	1500	79	.027	90
	AH-3	7.50	100	8½	.63	120	45	1400	74	.014	47
	AH-4	7.50	200	12½	.62	219	82	1300	68	.019	63
Series (II (high-sharpness)	AH-1*	7.50	10	12	0.68	340	128	1820	96	0.044	147
	AH-15	2.50	10	10	.64	316	119	1850	97	.047	157
	AH-16	1.00	10	11	.62	288	108	2000	105	.048	160
	AH-17	0.50	10	12	.63	347	130	2250	118	.050	167
	AH-18	0.25	10	20	.64	363	136	2300	121	.051	170
Kodak Developer D-76 (1:1)[b]				7	0.66	266	100	1900	100	0.030	100

All data from single runs except for:
a. average of 5 runs; b. average of 2 runs.

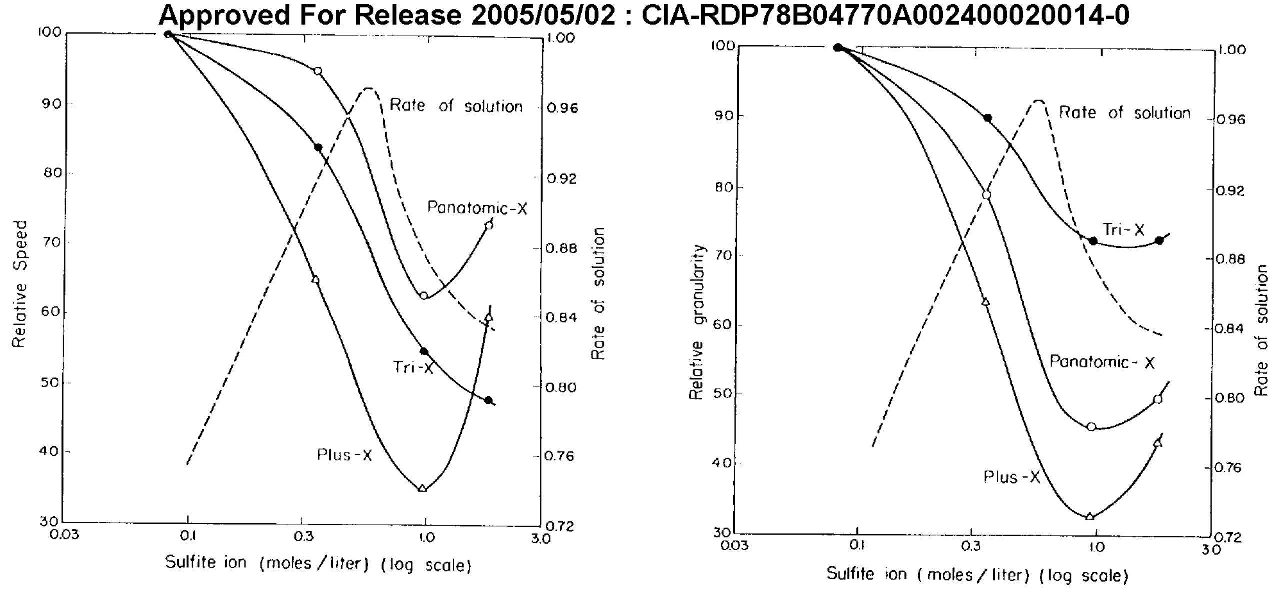
* Data repeated for convenience.

TABLE IV. Speed, Acutance, and Granularity of Kodak Tri-X Film

	Formula No.	Kodak Elon	Sulfite (g/l)	Dev. time (min)	γ	Speed	Speed %	Acutance	Acutance %	Granularity	Granularity %
Series I (fine-grain)	AH-1[a]	7.50	10	22	0.62	1090	128	950	79	0.074	132
	AH-2	7.50	30	20	.67	910	107	1150	96	.064	114
	AH-3	7.50	100	16	.65	590	70	700	58	.050	89
	AH-4	7.50	200	20	.64	525	62	500	42	.050	89
Series II (high-sharpness)	AH-1*	7.50	10	22	0.62	1090	128	950	79	0.074	132
	AH-15	2.50	10	11	.62	852	100	900	75	.082	147
	AH-16	1.00	10	11½	.62	795	94	900	75	.084	150
	AH-17	0.50	10	26	.67	795	94	1050	88	.086	154
	AH-18	0.25	10	35	.62	742	87	1150	96	.090	161
Kodak Developer D-76[b]				8½	0.63	850	100	1200	100	0.056	100

All data from single runs except for:
a. average of 5 runs; b. average of 2 runs.

* Data repeated for convenience.



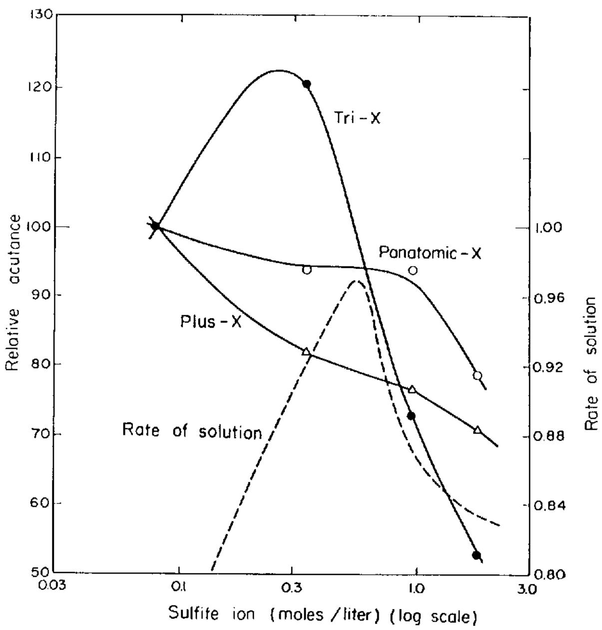


Fig. 1. Effect on three Kodak films of varying the sulfite concentration in the fine-grain series of developers. Abscissas, total sulfite ion, moles per liter (log scale); ordinates, relative values of indicated characteristics (arithmetic scale), with values for Developer AH-1 taken as 100%. Broken curves, relative rate of solution of silver (right-hand ordinate scale) according to Lee and James.

(middle graph), on the other hand, except for Tri-X Film, drop rather steadily with increasing sulfite concentration between 0.1 and 0.5 mole/liter. Plus-X Film is affected the most in speed and granularity and Tri-X the least by a change in sulfite concentration.

Figure 2 shows the results for the high-sharpness series of developers (Series II), with the values for AH-1 being again taken as 100%. Here the abscissas are in terms of Elon concentration in grams per liter. Speaking generally, reducing the Elon concentration does increase acutance without seriously reducing the speed except for Tri-X Film. However, it also increases granularity, especially of Panatomic-X Film.

Microstructure

Since, broadly speaking, fine-grain development and high-sharpness development have been found to be incompatible in these series of developers, we come next to the question of making the best choice between these competing qualities. Obviously a formula may be chosen to fit a specific use—for example, to emphasize speed or to minimize grain. But is it possible to relate the speed, grain, and acutance curves moving in different directions, and what is the relative importance of the three parameters? Although not much information is available on this problem, some recent work of Wolfe and Tuccio[9] does suggest one approach to it.

9. R. N. Wolfe and S. A. Tuccio, *Phot. Sci. & Eng.*, 4: 330 (1960).

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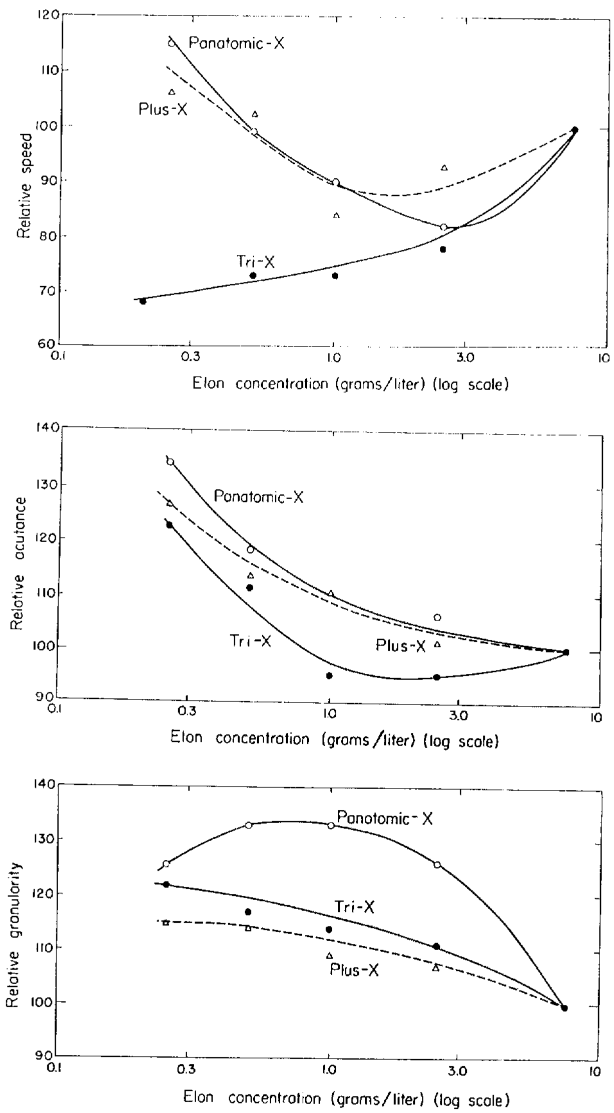

Fig. 2. Effect on three Kodak films of varying the Elon concentration in the high-sharpness series of developers. Abscissas, Elon concentration, grams per liter (log scale); ordinates, relative values of indicated characteristics (arithmetic scale), with values for Developer AH-1 taken as 100%.

In a study of the definition of aerial photographs—"definition" being specified as the characteristic that relates to the clarity with which detail is reproduced—these authors evaluated a series of pictures in terms of the quantity $(\sigma_B \cdot \sigma_G)^{-1}$ and found that this agreed well with the subjective judgments of definition made by a jury of observers on the pictures.

The factor $\sigma(_G)$ in this expression is the granularity of the emulsion and is expressed as the root-mean-square variation from average density indicated by a microdensitometer scanning a uniformly exposed and processed sample. The quantity σ_B was essentially the width of the composite spread-function for the entire photographic system, which in this case, involved a camera lens, the negative material, and the effects of image motion. Now it can be shown that the distribution of energy in a knife-edge exposure is given by the integral of the spread function between its end points, so that the width of the spread function and the width of the edge are much the same. Furthermore, when the shapes of the edge distributions are similar and gamma is held constant—as in the present experiment—we may say that acutance is roughly inversely proportional to the width of the edge trace. In others words, when we consider film and developer alone, the reciprocal of the σ_B of Wolfe and Tuccio is approximately proportional to acutance.

Since σ_G is the granularity of the emulsion, it seems reasonable in the present state of our knowledge to appraise the simultaneous variations of granularity and acutance in terms of the simple fraction, acutance/granularity. This ratio gives us a value for the microstructure properties of the image, and a high ratio shows good over-all microstructure properties.

It is also conceivable that increases in speed could lead to improvements in the over-all definition of the final picture, since such increases permit the use of smaller apertures or higher shutter speeds. However, we do not know quantitatively how increased depth of field or reduced subject movement is reflected in over-all picture quality.

We have therefore evaluated the simple ratio, acutance/granularity, at a density of unity for the various emulsion–developer combinations considered here, and these are given in Table V. The values are relative, with D-76 being taken as 100% to show the changes with developer variations. A value of over 100% indicates an improvement in the acutance/-granularity ratio with respect to D-76.

Inspection of this table shows that, in these experiments, variations in Elon and sulfite concentrations have resulted in very much greater changes in granularity than in acutance. This is why the fine-grain developers (Series I) in general appear to be advantageous on a combined basis; the improvement in granularity is proportionately so much greater than the loss in acutance. For the same reason, the high-sharpness developer formulas (Series II) in general are evaluated at less than 100%—one has paid a disproportionate price in granularity for a moderate gain in acutance.

Of course, as reference to Tables II–IV shows, the improvement in the microstructure ratio in Series I is accompanied by the expected loss in speed, so that under some circumstances this gain may not be realized in practice. Likewise, the losses exhibited by the emulsions in the Series II developers may be offset to some degree by increases in speed.

Informational Sensitivity

The acutance/granularity ratio appears at present to be a reasonable way to appraise simultaneous changes of graininess and sharpness in general photography. Recently there has also been described in the literature[10] a more specialized concept—informational sensitivity. Informational sensitivity is based on considerations of the minimum energy-increment detectable by a given photographic emulsion, and its relation to the granularity, spread function, and sensitometric characteristics of that emulsion. One application of this concept is in the design of complete photographic systems, that is, in the choice of optimum lens-film combinations. If the conditions are imposed that the physical size of the lens aperture be fixed but that lens focal length may be varied to use each film and developer combination to its best advantage, the informational-sensitivity value indicates the combination that will record a star in the shortest exposure time.

The expression given by Zweig, Higgins, and MacAdam for informational sensitivity at any given density is

$$\mathrm{IS} = g/a \cdot \sigma_D,$$

10. H. J. Zweig, G. C. Higgins, and D. L. MacAdam, *J. Opt. Soc. Am.*, 48: 926 (1958).

where g is the slope of the density-exposure (*not* D-log E) curve at this given density, a is the area of the emulsion spread-function, and σ_D is the rms-granularity of the emulsion at that density for a scanning aperture of area a. It can be shown that, when the same emulsion is processed to a constant gamma in a series of developers, g is proportional to the reciprocal of E_D, the exposure required to produce the reference density. Also, since acutance Ac is inversely proportional to r, the radius of the spread function, it turns out that

$$\mathrm{IS} \sim \frac{1}{E_D} \cdot \frac{Ac}{G}$$

where G is Selwyn granularity, $\sigma\sqrt{a}$.

It will be noted that this approximate conversion of the informational-sensitivity expression is similar to the Ac/σ_D quantity already employed, with the addition of a special type of speed term for this special application.

The informational sensitivity of the three emulsions used with the three developers was computed, since this may be of interest in some applications of

TABLE V. Relative Acutance/Granularity Ratio at Unit Net Density

	Formula No.	Kodak Elon (g/l)	Sulfite (g/l)	Kodak Panatomic-X Film	Kodak Plus-X Film	Kodak Tri-X Film
Series I (fine-grain)	AH-1	7.50	10	88	69	60
	AH-2	7.50	30	117	92	76
	AH-3	7.50	100	204	162	65
	AH-4	7.50	200	156	114	47
Series II (high-sharpness)	AH-1*	7.50	10	88	69	60
	AH-15	2.50	10	75	65	51
	AH-16	1.00	10	73	70	50
	AH-17	0.50	10	79	76	57
	AH-18	0.25	10	93	76	59
Kodak Developer D-76 (1:1)				100	100	100

* Data repeated for convenience.

TABLE VI. Relative Informational Sensitivity

	Formula No.	Kodak Elon (g/l)	Sulfite (g/l)	Kodak Panatomic-X Film	Kodak Plus-X Film	Kodak Tri-X Film
Series I (fine-grain)	AH-1	7.50	10	89	52	64
	AH-2	7.50	30	117	55	100
	AH-3	7.50	100	135	31	36
	AH-4	7.50	200	133	36	22
Series II (high-sharpness)	AH-1*	7.50	10	89	52	64
	AH-15	2.50	10	65	84	36
	AH-16	1.00	10	82	73	27
	AH-17	0.50	10	135	89	52
	AH-18	0.25	10	165	79	32
Kodak Developer D-76 (1:1)				100	100	100

* Data repeated for convenience.

photography. Table VI summarizes the results, with D-76 again being taken as 100%.

It should be noted that these values are given for a density of unity, that is, for a point moderately well up on the characteristic curve. Because of this, the $1/E_D$ term is rather sensitive to mismatches of gamma and to slight changes in curve shape, and this is reflected in some instances in the tabulated values. (For instance, we have observed that Plus-X Film, when processed in low-Elon developers, exhibits a distinct tendency to an upward concavity of the characteristic curve. This, of course, could be an advantage for some applications.) It may also be remarked that informational sensitivity is generally at its maximum at very low densities (see Ref. 10, Fig. 8).

At any rate, Table VI shows the manner in which informational sensitivity varies throughout these series of developers. It is apparent that useful gains over D-76 result, in these series of formulas, only with Panatomic-X Film.

Summary and Conclusions

A number of simple Elon–alkali developers were formulated, grouped into two series. In the first series, the silver-solvent (sulfite) content of the developer was systematically varied. In the second series, acutance was varied by systematic variations in Elon concentration.

In general, the first series of developers showed that large amounts of sulfite in connection with a high and constant Elon concentration resulted in decreases in acutance as well as decreases in granularity and speed. When sulfite concentrations in excess of about 1 mole/liter are used, the action reverses and granularity starts to increase again; acutance, however, continues to drop.

In the second series of developers, where the sulfite concentration is low and constant, moderate improvements in acutance result from lowering the Elon concentration. In all cases in this series, however, the granularity was found to be excessive for the resulting speed of the materials. Acutance continued to increase to the lowest concentration of Elon which was tried—0.25 gram/liter.

An attempt was made to appraise the combined effect of changes in both acutance and granularity (microstructure) on the over-all photographic definition of the negative in terms of the simple ratio of acutance to granularity, in accordance with the work of Wolfe and Tuccio. In general, because the variations in granularity produced by developer changes are much greater than the variations in acutance, fine-grain development appears to offer an advantage.

A simple approximate conversion of the Zweig-Higgins-MacAdam expression for informational sensitivity was introduced, and the various emulsion–developer combinations were evaluated with reference to this.

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* Kodak Elon Developing Agent is the Eastman Kodak Company trade name for *p*-methylaminophenol sulfate.

† The data presented in this paper are representative of the emulsions manufactured at the time the experiments were made. However, it must be recognized that the characteristics of products of the same name may vary within manufacturing tolerances and may change significantly as improvements are effected.

Experimental Details

Developer Formulas. The first step in the experiment was to formulate the appropriate series of developers. This was done by the sensitometric testing of preliminary formulas with the aim of establishing reasonably uniform activity levels and development times. The first section of Table I shows the composition of the fine-grain series (Series I).

TABLE I. Constituents of Developers

Series	Formula No.	Kodak Elon (g/l)	Sodium sulfite (anhydr.) (g/l)	Sodium bisulfite (g/l)	Total sulfite (M/l)	Kodalk (g/l)
I (fine-grain)	AH-1	7.50	10	0	0.08	4
	AH-2	7.50	30	5	0.29	0
	AH-3	7.50	100	15	0.95	0
	AH-4	7.50	200	20	1.80	0
II (high-sharpness)	AH-15	2.50	10	0	0.08	4
	AH-16	1.00	10	0	.08	6
	AH-17	0.50	10	0	.08	20
	AH-18	0.25	10	0	.08	20

The central formula in this series, AH-3, is essentially Kodak Developer D-25.[4] It is a true fine-grain developer, giving grain reduction at the expense of reduced emulsion speed. The solvent action has been lowered in the AH-1 and AH-2 formulas by decreasing the sulfite content. Since this reduction would lower the pH and the activity as well, most of the bisulfite was removed in AH-2 and Kodalk Balanced Alkali was added in AH-1. Formula AH-4 contains more than the usual amount of bisulfite. This maintenance of approximately constant activity was considered essential since Henn and Crabtree[1] have shown that graininess is affected by both activity and sulfite content.

The solvent action is obtained from the combined effect of the sulfite and bisulfite, and these are totaled as moles of sulfite ion in the table.

The composition of the second series of developers is given in the second section of the table. These developers are of the "high-sharpness" type, characterized by low sulfite content and decreasing Elon content. The AH-16 developer, containing 1 gram of Elon per liter, is similar to the Beutler high-sharpness developer, which contains 0.83 gram of Elon per liter of diluted developer; both AH-16 and Beutler's formula have low sulfite content and moderate alkalinity. The Elon contents of the AH-1, 15, 17, and 18 developers bracket this, varying from 7.5 to 0.25 grams/liter. They all contain 10 grams of sodium sulfite per liter and the proper amount of alkali to equalize the activity. Full compensation of activity was not possible in the case of AH-18, containing the least amount of Elon, but the others are matched reasonably well.

Procedure. Once the final formulas had been established, complete time-gamma studies were made, and times of development at 68°F for a gamma of 0.65 for all emulsion–developer combinations were chosen. Acutance, granularity, and sensitometric-control strips were then exposed and processed for the times indicated by these studies. Processing was in the sensitometric machine of Jones, Russell, and Beacham,[5] which gives strong and uniform agitation. The resultant strips were evaluated in accordance with standard practices described in the literature. The speeds which will be cited later in the paper are 0.3G speeds measured according to the familiar ASA criterion. Granularity was measured in terms of the root-mean-square of the granularity fluctuations.[6] The diameter of the scanning aperture was 24 μ and the sample density was unity. Acutance was measured as described by Perrin;[7] the sample density was also unity. Since the curve shapes were similar, a single number at a constant density is a reasonable indication of the behavior of the developers.

Results

The results are summarized in Tables II–IV, which give the results for Panatomic-X, Plus-X, and Tri-X Films, respectively. Kodak Developer D-76 is included for comparison[4] and is taken arbitrarily as 100%. The sulfite concentration is given in grams per liter. The data for AH-1 in Series I are repeated in connection with Series II because, in a sense, this developer also forms a part of the latter series.

Speed, Acutance, and Granularity. The results for the fine-grain series, AH-1 to AH-4, are shown in Fig. 1, where they are plotted on the basis of 100% for AH-1. The abscissas are in terms of moles of sulfite ion per liter. As the sulfite concentration is increased, the speed and the granularity (top and bottom graphs) of all three emulsions diminish to a minimum at about 1.0 mole/liter and then rise again. The broken line shows the rate of solution of silver as determined by Lee and James,[8] and this exhibits a maximum at about 0.6 mole/liter. Although the data are not sufficient to locate the minima for speed and granularity precisely, these minima fall near the maximum rate of solution, and the proximity may be regarded as more than accidental. (The speed curve for Tri-X Film as drawn does not show a minimum, but the data are insufficient to determine whether there may be a minimum between 1.0 and 1.8 moles/liter.) The curves of acutance

4. *Processing Chemicals and Formulas*, Eastman Kodak Company, Rochester, N.Y., 5th ed., 1954, p. 39.

5. L. A. Jones, M. E. Russell, and H. R. Beacham, *Jour. SMPE*, **28**: 73 (1937).
6. G. C. Higgins and K. F. Stultz, *J. Opt. Soc. Am.*, **49**: 925 (1959).
7. F. H. Perrin, *Jour. SMPTE*, **69**: 151 (1960).
8. W. E. Lee and T. H. James, private communication.

TABLE II. Speed, Acutance, and Granularity of Kodak Panatomic-X Film

	Formula No.	Kodak Elon	Sulfite (g/l)	Dev. time (min)	γ	Speed	%	Acutance	%	Granularity	%
Series I (fine-grain)	AH-1[a]	7.50	10	9	0.62	130	113	2340	106	0.027	123
	AH-2	7.50	30	8	.63	125	108	2200	100	.019	86
	AH-3	7.50	100	$8\frac{1}{4}$	.63	82	71	2200	100	.011	50
	AH-4	7.50	200	11	.63	96	83	1850	84	.012	55
Series II (high-sharpness)	AH-1*	7.50	10	9	0.62	130	113	2340	106	0.027	123
	AH-15	2.50	10	4	.61	107	93	2500	113	.034	155
	AH-16	1.00	10	5	.61	117	102	2550	116	.036	164
	AH-17	0.50	10	7	.69	129	112	2750	125	.036	164
	AH-18	0.25	10	13	.64	150	130	3100	141	.034	155
Kodak Developer D-76 (1:1)[b]				$6\frac{1}{2}$	0.62	115	100	2200	100	0.022	100

All data from single runs except for:
a. average of 5 runs; b. average of 2 runs.

* Data repeated for convenience.

TABLE III. Speed, Acutance, and Granularity of Kodak Plus-X Pan Film

	Formula No.	Kodak Elon	Sulfite (g/l)	Dev. time (min)	γ	Speed	%	Acutance	%	Granularity	%
Series I (fine-grain)	AH-1[a]	7.50	10	12	0.68	340	128	1820	96	0.044	147
	AH-2	7.50	30	$9\frac{1}{2}$	.62	224	84	1500	79	.027	90
	AH-3	7.50	100	$8\frac{1}{2}$	.63	120	45	1400	74	.014	47
	AH-4	7.50	200	$12\frac{1}{2}$	.62	219	82	1300	68	.019	63
Series (II (high-sharpness)	AH-1*	7.50	10	12	0.68	340	128	1820	96	0.044	147
	AH-15	2.50	10	10	.64	316	119	1850	97	.047	157
	AH-16	1.00	10	11	.62	288	108	2000	105	.048	160
	AH-17	0.50	10	12	.63	347	130	2250	118	.050	167
	AH-18	0.25	10	20	.64	363	136	2300	121	.051	170
Kodak Developer D-76 (1:1)[b]				7	0.66	266	100	1900	100	0.030	100

All data from single runs except for:
a. average of 5 runs; b. average of 2 runs.

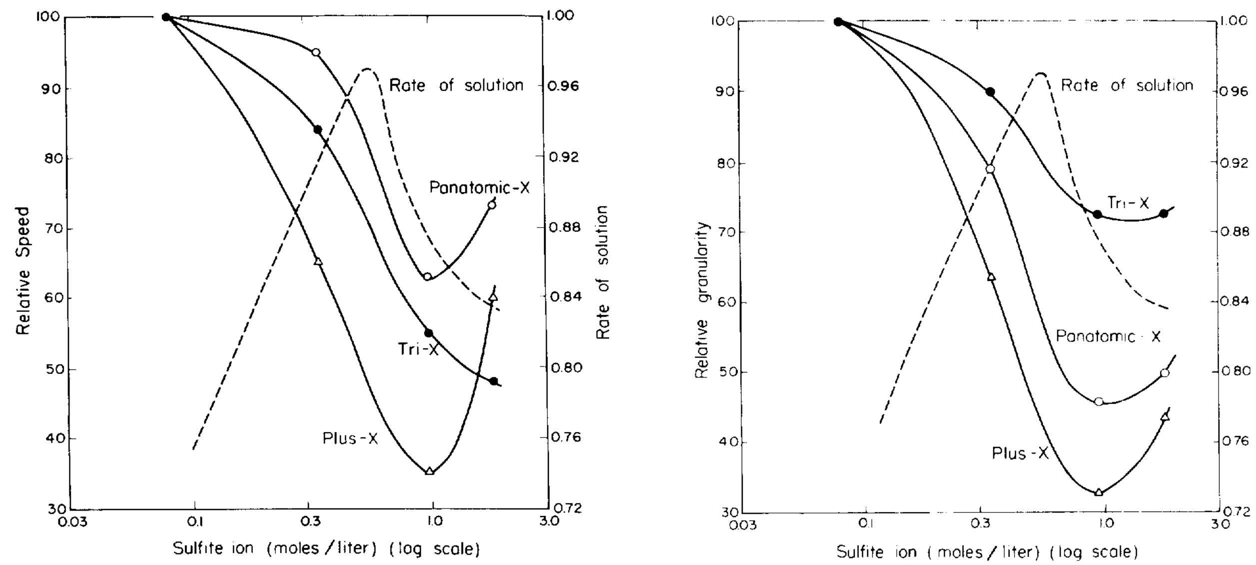
* Data repeated for convenience.

TABLE IV. Speed, Acutance, and Granularity of Kodak Tri-X Film

	Formula No.	Kodak Elon	Sulfite (g/l)	Dev. time (min)	γ	Speed	%	Acutance	%	Granularity	%
Series I (fine-grain)	AH-1[a]	7.50	10	22	0.62	1090	128	950	79	0.074	132
	AH-2	7.50	30	20	.67	910	107	1150	96	.064	114
	AH-3	7.50	100	16	.65	590	70	700	58	.050	89
	AH-4	7.50	200	20	.64	525	62	500	42	.050	89
Series II (high-sharpness)	AH-1*	7.50	10	22	0.62	1090	128	950	79	0.074	132
	AH-15	2.50	10	11	.62	852	100	900	75	.082	147
	AH-16	1.00	10	$11\frac{1}{2}$	.62	795	94	900	75	.084	150
	AH-17	0.50	10	26	.67	795	94	1050	88	.086	154
	AH-18	0.25	10	35	.62	742	87	1150	96	.090	161
Kodak Developer D-76[b]				$8\frac{1}{2}$	0.63	850	100	1200	100	0.056	100

All data from single runs except for:
a. average of 5 runs; b. average of 2 runs.

* Data repeated for convenience.



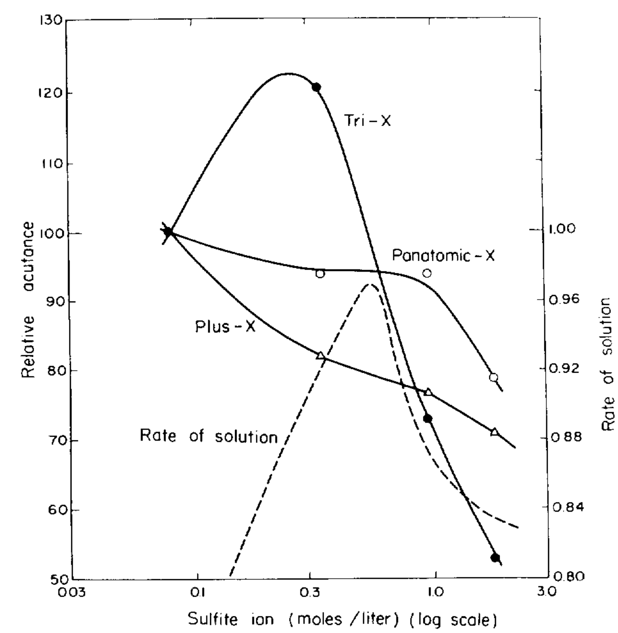


Fig. 1. Effect on three Kodak films of varying the sulfite concentration in the fine-grain series of developers. Abscissas, total sulfite ion, moles per liter (log scale); ordinates, relative values of indicated characteristics (arithmetic scale), with values for Developer AH-1 taken as 100%. Broken curves, relative rate of solution of silver (right-hand ordinate scale) according to Lee and James.

(middle graph), on the other hand, except for Tri-X Film, drop rather steadily with increasing sulfite concentration between 0.1 and 0.5 mole/liter. Plus-X Film is affected the most in speed and granularity and Tri-X the least by a change in sulfite concentration.

Figure 2 shows the results for the high-sharpness series of developers (Series II), with the values for AH-1 being again taken as 100%. Here the abscissas are in terms of Elon concentration in grams per liter. Speaking generally, reducing the Elon concentration does increase acutance without seriously reducing the speed except for Tri-X Film. However, it also increases granularity, especially of Panatomic-X Film.

Microstructure

Since, broadly speaking, fine-grain development and high-sharpness development have been found to be incompatible in these series of developers, we come next to the question of making the best choice between these competing qualities. Obviously a formula may be chosen to fit a specific use for example, to emphasize speed or to minimize grain. But is it possible to relate the speed, grain, and acutance curves moving in different directions, and what is the relative importance of the three parameters? Although not much information is available on this problem, some recent work of Wolfe and Tuccio[9] does suggest one approach to it.

9 R. N. Wolfe and S. A. Tuccio, *Phot. Sci. & Eng.*, **4**: 330 (1960)

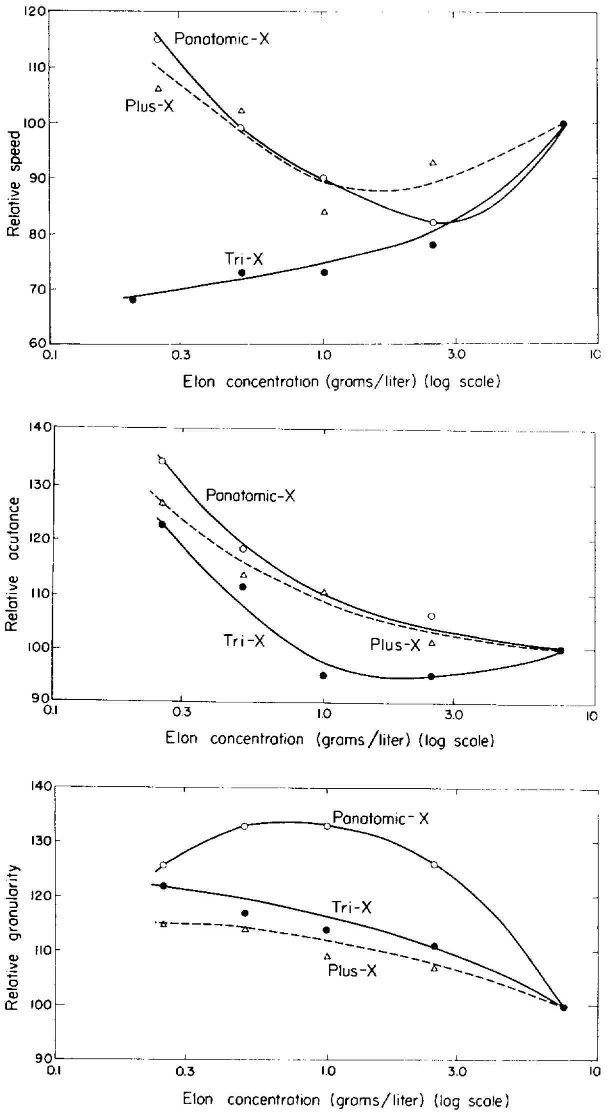


Fig. 2. Effect on three Kodak films of varying the Elon concentration in the high-sharpness series of developers. Abscissas, Elon concentration, grams per liter (log scale); ordinates, relative values of indicated characteristics (arithmetic scale), with values for Developer AH-1 taken as 100%.

In a study of the definition of aerial photographs—"definition" being specified as the characteristic that relates to the clarity with which detail is reproduced—these authors evaluated a series of pictures in terms of the quantity $(\sigma_B \cdot \sigma_G)^{-1}$ and found that this agreed well with the subjective judgments of definition made by a jury of observers on the pictures.

The factor $\sigma(_G)$ in this expression is the granularity of the emulsion and is expressed as the root-mean-square variation from average density indicated by a microdensitometer scanning a uniformly exposed and processed sample. The quantity σ_B was essentially the width of the composite spread-function for the entire photographic system, which in this case, involved a camera lens, the negative material, and the effects of image motion. Now it can be shown that the distribution of energy in a knife-edge exposure is given by the integral of the spread function between its end points, so that the width of the spread function and the width of the edge are much the same. Furthermore, when the shapes of the edge distributions are similar and gamma is held constant as in the present experiment—we may say that acutance is roughly inversely proportional to the width of the edge trace. In others words, when we consider film and developer alone, the reciprocal of the σ_B of Wolfe and Tuccio is approximately proportional to acutance.

Since σ_G is the granularity of the emulsion, it seems reasonable in the present state of our knowledge to appraise the simultaneous variations of granularity and acutance in terms of the simple fraction, acutance/granularity. This ratio gives us a value for the microstructure properties of the image, and a high ratio shows good over-all microstructure properties.

It is also conceivable that increases in speed could lead to improvements in the over-all definition of the final picture, since such increases permit the use of smaller apertures or higher shutter speeds. However, we do not know quantitatively how increased depth of field or reduced subject movement is reflected in over-all picture quality.

We have therefore evaluated the simple ratio, acutance/granularity, at a density of unity for the various emulsion–developer combinations considered here, and these are given in Table V. The values are relative, with D-76 being taken as 100% to show the changes with developer variations. A value of over 100% indicates an improvement in the acutance/granularity ratio with respect to D-76.

Inspection of this table shows that, in these experiments, variations in Elon and sulfite concentrations have resulted in very much greater changes in granularity than in acutance. This is why the fine-grain developers (Series I) in general appear to be advantageous on a combined basis; the improvement in granularity is proportionately so much greater than the loss in acutance. For the same reason, the high-sharpness developer formulas (Series II) in general are evaluated at less than 100%—one has paid a disproportionate price in granularity for a moderate gain in acutance.

Of course, as reference to Tables II–IV shows, the improvement in the microstructure ratio in Series I is accompanied by the expected loss in speed, so that under some circumstances this gain may not be realized in practice. Likewise, the losses exhibited by the emulsions in the Series II developers may be offset to some degree by increases in speed.

Informational Sensitivity

The acutance/granularity ratio appears at present to be a reasonable way to appraise simultaneous changes of graininess and sharpness in general photography. Recently there has also been described in the literature[10] a more specialized concept—informational sensitivity. Informational sensitivity is based on considerations of the minimum energy-increment detectable by a given photographic emulsion, and its relation to the granularity, spread function, and sensitometric characteristics of that emulsion. One application of this concept is in the design of complete photographic systems, that is, in the choice of optimum lens–film combinations. If the conditions are imposed that the physical size of the lens aperture be fixed but that lens focal length may be varied to use each film and developer combination to its best advantage, the informational-sensitivity value indicates the combination that will record a star in the shortest exposure time.

The expression given by Zweig, Higgins, and MacAdam for informational sensitivity at any given density is

$$\mathrm{IS} = g/a \cdot \sigma_D,$$

10. H. J. Zweig, G. C. Higgins, and D. L. MacAdam, *J. Opt. Soc. Am.*, **48:** 926 (1958).

where g is the slope of the density-exposure (*not* D-log E) curve at this given density, a is the area of the emulsion spread-function, and σ_D is the rms-granularity of the emulsion at that density for a scanning aperture of area a. It can be shown that, when the same emulsion is processed to a constant gamma in a series of developers, g is proportional to the reciprocal of E_D, the exposure required to produce the reference density. Also, since acutance Ac is inversely proportional to r, the radius of the spread function, it turns out that

$$\mathrm{IS} \sim \frac{1}{E_D} \cdot \frac{Ac}{G}$$

where G is Selwyn granularity, $\sigma\sqrt{a}$.

It will be noted that this approximate conversion of the informational-sensitivity expression is similar to the Ac/σ_D quantity already employed, with the addition of a special type of speed term for this special application.

The informational sensitivity of the three emulsions used with the three developers was computed, since this may be of interest in some applications of

TABLE V. Relative Acutance/Granularity Ratio at Unit Net Density

	Formula No.	Kodak Elon (g/l)	Sulfite (g/l)	Kodak Panatomic-X Film	Kodak Plus-X Film	Kodak Tri-X Film
Series I (fine-grain)	AH-1	7.50	10	88	69	60
	AH-2	7.50	30	117	92	76
	AH-3	7.50	100	204	162	65
	AH-4	7.50	200	156	114	47
Series II (high-sharpness)	AH-1*	7.50	10	88	69	60
	AH-15	2.50	10	75	65	51
	AH-16	1.00	10	73	70	50
	AH-17	0.50	10	79	76	57
	AH-18	0.25	10	93	76	59
Kodak Developer D-76 (1:1)				100	100	100

* Data repeated for convenience.

TABLE VI. Relative Informational Sensitivity

	Formula No.	Kodak Elon (g/l)	Sulfite (g/l)	Kodak Panatomic-X Film	Kodak Plus-X Film	Kodak Tri-X Film
Series I (fine-grain)	AH-1	7.50	10	89	52	64
	AH-2	7.50	30	117	55	100
	AH-3	7.50	100	135	31	36
	AH-4	7.50	200	133	36	22
Series II (high-sharpness)	AH-1*	7.50	10	89	52	64
	AH-15	2.50	10	65	84	36
	AH-16	1.00	10	82	73	27
	AH-17	0.50	10	135	89	52
	AH-18	0.25	10	165	79	32
Kodak Developer D-76 (1:1)				100	100	100

* Data repeated for convenience.

photography. Table VI summarizes the results, with D-76 again being taken as 100%.

It should be noted that these values are given for a density of unity, that is, for a point moderately well up on the characteristic curve. Because of this, the $1/E_D$ term is rather sensitive to mismatches of gamma and to slight changes in curve shape, and this is reflected in some instances in the tabulated values. (For instance, we have observed that Plus-X Film, when processed in low-Elon developers, exhibits a distinct tendency to an upward concavity of the characteristic curve. This, of course, could be an advantage for some applications.) It may also be remarked that informational sensitivity is generally at its maximum at very low densities (see Ref. 10, Fig. 8).

At any rate, Table VI shows the manner in which informational sensitivity varies throughout these series of developers. It is apparent that useful gains over D-76 result, in these series of formulas, only with Panatomic-X Film.

Summary and Conclusions

A number of simple Elon–alkali developers were formulated, grouped into two series. In the first series, the silver-solvent (sulfite) content of the developer was systematically varied. In the second series, acutance was varied by systematic variations in Elon concentration.

In general, the first series of developers showed that large amounts of sulfite in connection with a high and constant Elon concentration resulted in decreases in acutance as well as decreases in granularity and speed. When sulfite concentrations in excess of about 1 mole/liter are used, the action reverses and granularity starts to increase again; acutance, however, continues to drop.

In the second series of developers, where the sulfite concentration is low and constant, moderate improvements in acutance result from lowering the Elon concentration. In all cases in this series, however, the granularity was found to be excessive for the resulting speed of the materials. Acutance continued to increase to the lowest concentration of Elon which was tried (0.25 gram/liter.

An attempt was made to appraise the combined effect of changes in both acutance and granularity (microstructure) on the over-all photographic definition of the negative in terms of the simple ratio of acutance to granularity, in accordance with the work of Wolfe and Tuccio. In general, because the variations in granularity produced by developer changes are much greater than the variations in acutance, fine-grain development appears to offer an advantage.

A simple approximate conversion of the Zweig-Higgins-MacAdam expression for informational sensitivity was introduced, and the various emulsion-developer combinations were evaluated with reference to this.